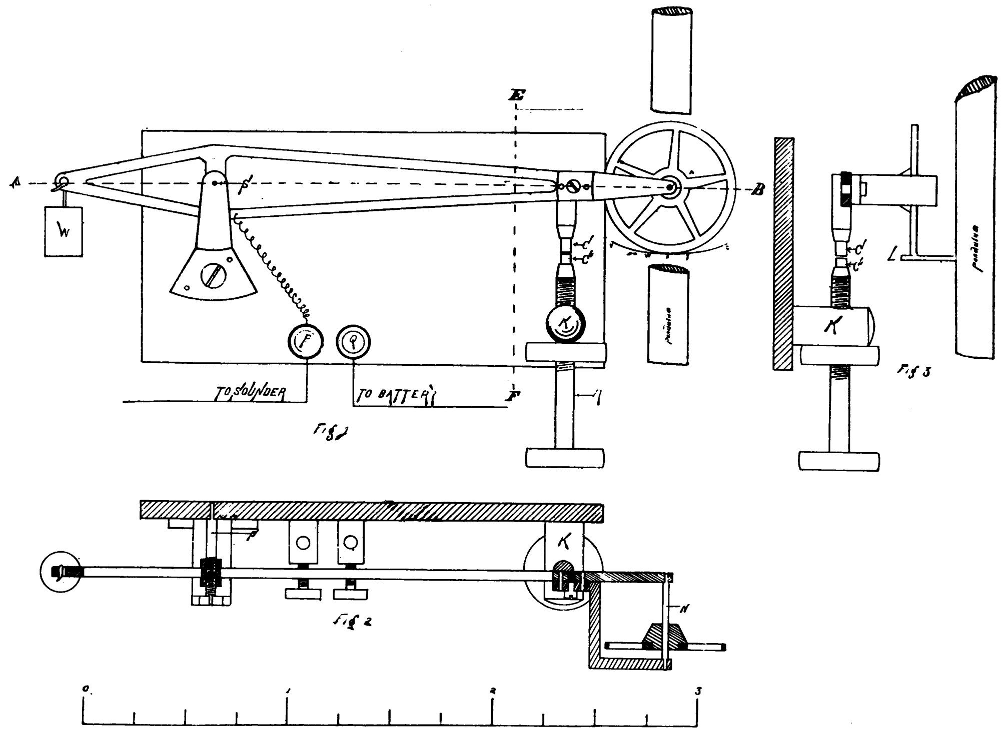
A NEW CIRCUIT-BREAKER FOR ASTRONOMICAL CLOCKS.

By A. F. Poole.

Various devices have been invented for sending regular electric signals from a clock, but none of them have given entire satisfaction when applied to clocks having the Graham dead-beat escapement. The trouble arises principally from the mode of operation of this escapement. In it the energy of the falling weight is given *directly* to the pendulum, there being no provision for correcting inequalities in the motive force, as is the case with a gravity escapement. One of the chief factors in a good clock rate is the absolute uniformity of the impulse given to the pendulum at each vibration. If this impulse varies, the clock rate will vary with it. Any circuit-breaker, applied to a dead-beat clock, must of necessity be worked either directly by the pendulum or by a part of the force which gives the impulse to the pendulum. In either case, if the work required to operate the breaker is variable, the effective impulse given to the pendulum will also be variable, and so also will be the clock rate. From this we have, at once, the conditions which must be fulfilled by a satisfactory circuit-breaker for a clock having a Graham escapement, viz.: the work done in breaking the circuit each time a signal is sent should be absolutely constant. It is also desirable, though not essential, that this work be as small as possible.

It was with the view of fulfilling the conditions of having the work both constant and small that I made the circuit-breaker described in this article. By means of a series of experiments made in the Physical Laboratory of the Leland Stanford Jr. University, I have investigated the work required to operate this instrument. Through the kindness of Professors Holden and Tucker, its efficiency, in actual use, has been tested on one of the Hohwu clocks of the Lick Observatory. Professor Tucker's account of its performance is given in an article immediately following. A description of the instrument and an account of the laboratory experiments are given in the following paragraphs.

An idea of the breaker can be obtained from the accompanying cut. Three views are given: Figure 1 is a plan, figure 2 a hor-



A NEW CIRCUIT-BREAKER FOR ASTRONOMICAL CLOCKS.

izontal section through the center of the beam AB, figure 3 is a vertical section through DE. A scale of inches is given at the bottom of the cut.

The breaker consists of a light metallic beam, pivoted at S; at the end of the beam is a light wheel, which is free to turn about the staff N; at the other end is a counterpoise, W. A platinum contact-point, c, is also mounted on the beam. The beam is insulated from the plate by having the pivots of the shaft S turn in garnet jewels. The point c rests on a similar point, c', mounted at the end of a screw of fine pitch, M, which screws into the post K, thus permitting the height of c' above K to be adjusted. The post K is screwed into the base-plate. P and Q are binding-posts; Q is in electrical connection with the base-plate, and P is insulated from it.

The current comes from one pole of the battery to the binding-post Q; from there through the base-plate to K; thence to M and to c'; then to c and to the beam, which is connected to the insulated post P by a fine copper wire. From P, the current passes through the sounder, or relay, to the other pole of the battery. When c rests on c', the circuit is complete, and when c is lifted from c', the circuit is broken.

The breaker is attached to the back of the clock-case, at a convenient distance—say about eighteen inches—below the suspension-spring, the plane of the beam AB being parallel to the plane of the pendulum's swing, and at such a distance behind it that the pendulum-rod clears the wheel by about ¼ inch. On the back of the pendulum-rod, and perpendicular to it, is a pin, L (figure 3), which engages the under side of the wheel at each vibration and slightly raises it, lifting c from c', and breaking the circuit.

In figure 1, v–w–x–y–z is the path of the pin L. It will be seen that the arc of contact of L with the wheel is but a small part of the entire arc.

The action of the breaker is as follows: Starting with the pendulum at the extreme left point of its swing, the pin L being at v, it swings in the direction of the arrow, and the pin L comes in contact with the wheel when it arrives at w. From w to y the pin passes under the wheel, thereby lifting the beam through a small distance. This separates c and c', and breaks the circuit. The pin leaves the wheel at y, and the circuit is again closed. The pendulum swings on to z, the extreme right point of its

swing. On its return the action is repeated in reverse order.

The beam is lifted a constant distance each time the circuit is broken; the mass of the beam is constant; hence, constancy in the work required each time to break the circuit is secured.

Before trying the breaker in actual service on a clock, I made a series of experiments with it to determine the amount of work needed to operate it. These experiments were of two kinds: first, to determine what pressure between c and c' would insure a safe and certain electrical connection; and, second, to determine the amount of work required to operate it, by observing its effect on a freely swinging pendulum.

In order to determine the pressure between c and c', the breaker was placed under a balance, and a fine silk fibre was attached between the wheel and balance-arm in such a way that c and c' could be separated by putting a sufficient weight in the other balance-pan. By measuring the pressure corresponding to four different values of the counterpoise W, I obtained

$$P = 1.395 - 0.24\ W,$$

in which the pressure P and the counterpoise W are expressed in grams.

The breaker was then put in the circuit of a battery and sounder, and different counterpoises used to find the least pressure between c and c' which would give a safe electrical connection. A counterpoise of 5.13 grams was found to be the largest value of W permissible. This value of W, by the above equation, corresponds to $P = 0.16$ grams.

But, if we take the work done in breaking the contact as the raising of 0.16 grams through a space of 0.15 millimeters,— this being the amount of separation of c and c' at each vibration, — we shall find that this is greater than the actual work required. While it is true that the pendulum does that much work on the breaker while L goes from w to x, it is also true that while L goes from x to y the breaker does work on the pendulum, since the beam is then falling to its original position. A large part of the work required to break the circuit is, therefore, given back to the pendulum. It was with the view of determining what per cent of the work done on the breaker is given back to the pendulum that the following experiments were made.

A pendulum was made having a length of 77.3 cm. and a bob weighing 960 grams. It vibrated sixty-eight times a min-

ute. A fine pointer was attached to the bottom of the bob, and a stationary scale was placed behind it. The arc of vibration was then read by means of a telescope at a distance of about twenty feet The arc of the pendulum's swing could be read with a probable error of not more than one minute of arc.

The pendulum was set swinging, and its arc of vibration read. After swinging freely for one hour the arc was again read. The arc had, of course, decreased, owing to the friction of the suspension-spring and the resistance of the air.

The breaker was then adjusted, and the pendulum again set swinging through the same arc as before. Readings were again taken at the beginning and end of the hour. The arc was further decreased, owing to the added resistance of the breaker.

At the end of the first hour the pendulum was swinging through an angle θ on either side of the vertical, and at the end of the second hour, during which the breaker had been in operation, through an angle ϕ. Evidently $\theta - \phi$ is the decrease in arc due to the resistance of the breaker during the hour, and the difference between the potential energy which the pendulum had at the angle θ and at ϕ is the energy which had been used in working the breaker one hour. The work done on the breaker is given by the expression

$$d\,(\cos\phi - \cos\theta)\ W',$$

in which W' is the weight of the bob, and d is the distance from the point of support to the center of gravity of the bob. All the quantities in this expression are known by measurement, and the work may, therefore, be computed.

In the first experiment, with the breaker off, at the beginning of the hour the arc of vibration of the pendulum on either side of the zero was $2^\circ\ 36'$, and at the end of the hour $1^\circ\ 9'$, giving a decrease of $1^\circ\ 27'$. With the breaker on, the reading at the beginning of the hour was $2^\circ\ 37'$; at the end of the hour $1^\circ\ 4'$, a decrease of $1^\circ\ 33'$. The decrease due to the breaker was $6'$, and by the formula above the work done by the pendulum in working the breaker was 2.49 centimeter-grams.

By the second experiment, $\theta = 0^\circ\ 50'$, and $\phi = 0^\circ\ 42'$, and the work, as before, was 2.32 centimeter-grams. These two results agree well within the limits of accuracy of observation.

The pendulum made 4080 beats an hour. The force at the wheel was 0.16 grams. At each swing of the pendulum the

wheel was lifted 0.015 centimeters. These data give 9.97 centimeter-grams as the amount of work which would be required to operate the breaker, provided none of the energy was given back to the pendulum. The work actually used — 2.40 centimeter-grams, the mean of the results of the two experiments, — is very approximately twenty-five per cent of this. From this, it follows that the breaker gives back to the pendulum about seventy-five per cent of the work required to break the circuit.

As stated above, the breaker is now in use on one of the HOHWU clocks at the LICK Observatory, and its performance has been very satisfactory, there being a difference of only 0.05 seconds in the mean daily rate of the clock caused by the breaker. And, furthermore, since it is not the difference which a breaker makes in the rate of a clock to which it is applied, but the variation of that difference, that is harmful, the bad effect of this breaker on any clock to which it may be applied will be very small indeed.

When the breaker is arranged as described above, there is no way of identifying the beginning of the minutes, since a signal is sent every second. If the clock-face is easily accessible, this is not a serious objection. When the clock signals are to be read at a distance, and when it is necessary for several seconds to be left out at the beginning of a new minute, the breaker, instead of being operated by a pin from the pendulum-rod, may be lifted by the teeth of a light wheel mounted on the 'scape-wheel staff. The proper teeth of this wheel are cut away to leave out the seconds desired.

It is believed that this breaker will secure almost absolute uniformity in the work required to break the circuit — a thing which has not been secured by any of the devices employing springs or mercury. It has also the advantage of being easy of adjustment. The height of the wheel above the post K being regulated by the screw M, can be readily raised or lowered, making the contact of L with the wheel just sufficient to break the circuit, and no more.

LELAND STANFORD JR. UNIVERSITY, June 27, 1895.